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Description

AIRFOIL COOLING HOLES

BACKGROUND OF INVENTION

[0001] The present invention relates generally to gas turbines and more particularly relates to cooling air circuits within a turbine airfoil.

[0002] Generally described, gas turbine buckets may have airfoil shaped body portions. The buckets may be connected at their inner ends to root portions and connected at their outer ends to tip portions. The buckets also may incorporate shrouds at these tip portions. Each shroud cooperates with like elements on adjacent buckets to prevent hot gas leakage past the tips. The use of the shrouds also may reduce vibrations.

[0003] The tip shrouds, however, may be subject to creep damage due to the combination of high temperatures and centrifugally induced bending stresses. One method of cooling each bucket as a whole is to use a number of cooling holes. The cooling holes may transport cooling air through the bucket and form a thermal barrier between

the bucket and the flow of hot gases.

[0004] Although cooling the buckets may reduce creep damage, the use of cooling air to cool the bucket may reduce the efficiency of the gas turbine as a whole due to the fact that this cooling air is not passing through the turbine section. The cooling air flow therefore should be at a minimum speed for the part. Likewise, the cooling holes may require optimization of the hole location, size, and style.

[0005] What is desired, therefore, is a cooling hole scheme for a turbine bucket that limits the reduction in overall system efficiency while providing adequate cooling to prevent creep. The scheme preferably also should increase part life.

SUMMARY OF INVENTION

[0006] The present invention thus provides an airfoil. The airfoil may include a first number of cooling holes and a second number of cooling holes positioned within the airfoil. The first number of cooling holes and the second number of cooling holes each may include a turbulated section and a non-turbulated section.

[0007] The first number of cooling holes may include five (5) cooling holes. The first number of cooling holes may include a first end and a second end such that the turbu-

lated section extends from about thirty-five percent (35%) of the length from the first end to about seventy-five percent (75%) of the length. The turbulated section of the first number of cooling holes may include a first diameter, the non-turbulated section may include a second diameter, and the first diameter may be larger than the second diameter. The turbulated section may have a diameter of about 0.175 inches (about 4.45 millimeters) and the non-turbulated section may have a diameter of about 0.135 inches (about 3.43 millimeters). The turbulated section may include ribs therein. A number of non-turbulated sections may be used.

[0008] The second number of cooling holes may include two (2) cooling holes. The second number of cooling holes may include a first end and a second end such that the turbulated section extends from about fifty percent (50%) of the length from the first end to about seventy-five percent (75%) of the length. The turbulated section of the second number of cooling holes may include a first diameter, the non-turbulated section may include a second diameter, and the first diameter may be larger than the second diameter. The turbulated section may have a diameter of about 0.165 inches (about 4.19 millimeter) and the non-

turbulated section may have a diameter of about 0.125 inches (about 3.18 millimeters). A number of non-turbulated sections may be used.

[0009] The airfoil further may include a third number of cooling holes positioned within the airfoil. The third number of cooling holes may include a non-turbulated section. The non-turbulated section may include a diameter of about 0.115 inches (about 2.92 millimeters). The first number of cooling holes, the second number of cooling holes, and the third number of cooling holes may include nine (9) cooling holes.

[0010] The airfoil further may include a tenth cooling hole positioned therein. The tenth cooling hole may include a diameter of about 0.08 inches (about 2.03 millimeters).

[0011] A further embodiment of the present invention may provide an airfoil for use with a turbine. The airfoil may include a first end, a middle portion, and a second end. The airfoil may include a number of cooling holes extending through the first end, the middle portion, and the second end. The cooling holes may be positioned in the first end according to the Cartesian coordinate values set forth in Table I and the cooling holes may be positioned in the middle portion according to the Cartesian coordinate val-

ues set forth in Table III. The cooling holes may be positioned in the second end according to the Cartesian coordinate values set forth in Table II. The airfoil may be a second stage airfoil.

[0012] These and other features of the present invention will become apparent upon review of the following detailed description when taken in conjunction with the drawings and the appended claims.

BRIEF DESCRIPTION OF DRAWINGS

[0013] Fig. 1 is a partial side plan view of a turbine section.

[0014] Fig. 2 is a side cross-sectional view of a bucket showing the cooling holes.

[0015] Fig. 3 is a side cross-sectional view of a bucket showing select cooling holes.

[0016] Fig. 4 is a side cross-sectional view taken along line 4-4 of Fig. 3.

[0017] Fig. 5 is a side cross-sectional view taken along line 5-5 of Fig. 3.

[0018] Fig. 6 is a top cross-sectional view of the bucket taken along line 6-6 of Fig. 3.

[0019] Fig. 7 is a top cross-sectional view of the bucket taken along line 7-7 of Fig. 3.

[0020] Fig. 8 is a top cross-sectional view of the bucket taken along line 8-8 of Fig. 3.

DETAILED DESCRIPTION

[0021] Referring now to the drawings, in which like numerals refer to like elements throughout the several views, Fig. 1 shows a turbine section *10* of a gas turbine. The turbine section *10* of the gas turbine is downstream of the turbine combustor *20*. The turbine section includes a rotor, generally designated *R*, with four successive stages. These stages include a first stage *30*, a second stage *40*, a third stage *50*, and a fourth stage *60*. Each stage includes a row of buckets, a first bucket *70*, a second bucket *80*, a third bucket *90*, and fourth bucket *100*. The blades of the buckets *70*, *80*, *90*, *100* project radially outward into the hot combustion gas path of the turbine section *10*. The buckets *70*, *80*, *90*, *100* are arranged alternatively between fixed nozzles, a first nozzle *110*, a second nozzle *120*, a third nozzle *130*, and a fourth nozzle *140*. The stages *30*, *40*, *50*, *60* also may be separated by a number of spacers, a first spacer *150*, a second spacer *160*, and a third spacer *170*. The stages *30*, *40*, *50*, *60* and the spacers *150*, *160*, *170* may be secured to one another by a plurality of circumferentially spaced axially extending bolts *180* (one shown).

[0022] Figs. 2 and 3 show a bucket *200* of the present invention. The bucket *200* may be the second bucket *80* on the second stage *40*. Specifically, The General Electric Company of Schenectady, New York may use this configuration for the second stage bucket of a "9FA+e"or a "7FA+e"turbine sold. The bucket *200* may be made out of a directionally solidified alloy such as DS GTD- 111™ also sold by The General Electric Company.

[0023] The bucket *200* may include a blade or an airfoil portion *210*. The airfoil *210* may have a profile intended to generate aerodynamic lift. The airfoil *210* may have a leading edge *220* generally oriented upstream towards the combustor *20* and a trailing edge *230* generally oriented downstream towards the exhaust section of the turbine assembly.

[0024] One end of the airfoil *210* may extend from a blade platform *240*. The blade platform *240* may define the inner radius of the hot gas flow path. The blade platform *240* also may provide a barrier between the hot gas and the inboard systems. The blade platform *240* may be connected to a blade attachment portion *250*. The blade attachment portion *250* may attach the bucket *200* to the turbine shaft.

[0025] The other end of the airfoil *210* may include a tip shroud

260. The tip shroud *260* may extend beyond the edges of the airfoil *210* to form a shelf *270*. The tip shroud *260* also may include a sealing rail *280* extending in the direction of the airfoil *210*. The shelf *270* and the sealing rail *280* may reduce the spillover of hot gases by decreasing the size of the clearance gap and interrupting the hot gas path around the end of the bucket *200*.

[0026] As is shown in Fig. 2, the bucket *200* may include a number of cooling holes *290*. In this case, the bucket *200* may include ten (10) cooling holes *290*, a first cooling hole *300*, a second cooling hole *310*, a third cooling hole *320*, a fourth cooling hole *330*, a fifth cooling hole *340*, a sixth cooling hole *350*, a seventh cooling hole *360*, an eighth cooling hole *370*, a ninth cooling hole *380*, and a tenth hole *390*. Although ten (10) cooling holes *290* are shown, any number of cooling holes *290* may be used. The cooling holes *290* may extend from the tip shroud *260*, through the airfoil *210*, and through the blade attachment *250*.

[0027] As is shown in Fig. 3, the cooling holes *290* may be turbulated for part or all of their length. The thermal barrier formed by the cooling air stream exiting the cooling holes *290* may be improved by providing a turbulent air stream.

One means of making turbulated cooling holes is shown in commonly owned U.S. Patent No. 6,539,627, incorporated herein by reference.

[0028] For example, Fig. 3 shows one (1) of the first five (5) cooling holes *300*, *310*, *320*, *330*, *340*. These cooling holes *300*, *310*, *320*, *330*, *340* may be turbulated for a portion of their length through the airfoil *210*. In this example, the turbulated area may start at about thirty-five percent (35%) of the length of the airfoil *210* from the blade platform *240*. The turbulated area may finish at about seventy-five percent (75%) of the airfoil *210* length. The cooling holes *300*, *310*, *320*, *330*, *340* thus may have a smooth area *400* and a turbulated area *410*. The smooth area *400* may have a diameter of about 0.135 inches (about 3.43 millimeters). The turbulated area *410* may be somewhat expanded and includes a series of ribs *420* as is shown in Fig. 4. The turbulated area *410* may have a diameter of about 0.175 inches (about 4.45 millimeters). The use of the expanded area with the ribs *420* promotes turbulent airflow. As is shown, the turbulated area *410* may be positioned between two (2) smooth areas *400*. Of the five (5) cooling holes *300*, *310*, *320*, *330*, *340*, four (4) cooling holes may have airflow in the upstream direction and one may have

airflow in the downstream direction. Any direction or combination of directions, however, may be used.

[0029] Referring again to Fig. 3, cooling holes six (6) and seven (7) *350*, *360* also may use the smooth areas *400* and the turbulated area *410*. The turbulated area *410* may start at about fifty percent (50%) of the length of the airfoil *210* and end at about seventy-five percent (75%) of the length. The smooth areas *400* may have a diameter of about 0.125 inch (about 3.18 millimeters). The turbulated area *410* may have a diameter of about 0.165 inches (about 4.19 millimeter). The turbulated area *410* may include the ribs *420* as is shown in Fig. 5. The cooling holes six (6) and seven (7) *350*, *360* may direct the air in the down-stream direction.

[0030] Cooling holes eight (8) and nine (9) *370*, *380* may have a smooth area *400* throughout. These cooling holes *370*, *380* may have a diameter of about 0.115 inches (about 2.92 millimeters) and may have a flow in the downstream di-rection. The tenth (10th) cooling hole *390* also may have a smooth area *400* throughout its length. The tenth (10th) cooling hole *390* may have a diameter of about 0.08 inches (about 2.03 millimeters) and may have a flow in the downstream direction.

[0031] Figs. 6-8 show the location and the configuration of the cooling holes *290* as they extend through the bucket *200*. Fig. 6 shows the location of the cooling holes *290* along line 6-6 of Fig. 3. Fig. 7 shows the location of the cooling holes *290* along line 7-7 of Fig. 3. Fig 8 shows the location of the cooling holes *290* along line 8-8 of Fig. 3. Each of the figures described above has an X and a Y axis superimposed thereon. The following chart shows the coordinates for each of the cooling holes *290*:

Table I: Section 6-6:

	"X"	"Y"
Hole **300**	-1.561 inch (-39.65 mm)	1.714 inch (43.54 mm)
Hole **310**	-1.272 inch (-32.31 mm)	1.672 inch (42.47 mm)
Hole **320**	-1.008 inch (-25.60 mm)	1.543 inch (39.19 mm)
Hole **330**	-0.794 inch (-19.91 mm)	1.377 inch (34.98 mm)
Hole **340**	0.167 inch (4.24 mm)	0.627 inch (15.93 mm)
Hole **350**	0.395 inch (10.03 mm)	0.347 inch (8.81 mm)
Hole **360**	0.604 inch (15.34 mm)	0.099 inch (2.51 mm)
Hole **370**	0.858 inch (21.79 mm)	-0.174 inch (-4.42 mm)
Hole **380**	1.115 inch (28.32 mm)	-0.445 inch (-11.30 mm)
Hole **390**	1.378 inch (35.00 mm)	-0.720 inch (-18.29 mm)

Table II - Section 7-7:

Hole	"X"	"Y"
Hole **300**	-1.810 inch (-45.97 mm)	-0.872 inch (-22.1597 mm)
Hole **310**	-1.601 inch (-40.6697 mm)	-0.319 inch (-8.1097 mm)
Hole **320**	-1.170 inch (-29.7297 mm)	0.166 inch (4.2297 mm)
Hole **330**	-0.618 inch (-15.7097 mm)	0.476 inch (12.0997 mm)
Hole **340**	-0.017 inch (-0.4397 mm)	0.555 inch (14.1097 mm)
Hole **350**	0.431 inch (10.9597 mm)	0.382 inch (9.7097 mm)
Hole **360**	0.960 inch (24.3897 mm)	0.153 inch (3.89097 mm)
Hole **370**	1.412 inch (35.8697 mm)	-0.227 inch (-5.7797 mm)
Hole **380**	1.826 inch (46.3897 mm)	-0.585 inch (-14.8697 mm)
Hole **390**	2.224 inch (56.4997 mm)	0.955 inch (24.2697 mm)

Table III - Section 8-8:

Hole	"X"	"Y"
Hole **300**	-2.209 inch (56.11 mm)	0.710 inch (18.03 mm)
Hole **310**	-1.783 inch (-45.29 mm)	0.530 inch (13.46 mm)
Hole **320**	-1.377 inch (-34.98 mm)	0.363 inch (9.23 mm)
Hole **330**	-0.979 inch (-24.86 mm)	0.218 inch (5.55 mm)
Hole **340**	-0.579 inch (-3.971 mm)	0.099 inch (2.51 mm)
Hole **350**	-0.156 inch (-3.97 mm)	0.001 inch (0.02 mm)
Hole **360**	0.260 inch (6.601 mm)	-0.089 inch (-2.27 mm)
Hole **370**	0.688 inch (17.48 mm)	-0.166 inch (-4.21 mm)
Hole **380**	1.120 inch (28.45 mm)	-0.245 inch (-6.23 mm)
Hole **390**	1.554 inch (39.46 mm)	-0.324 inch (-8.24 mm)

[0032] The positioning of the cooling holes *290* as described above provides superior cooling based upon the number of cooling holes *290* and their respective size, shape, style, and location. The size of the cooling holes *290* may

limit the amount of airflow based on the pressure difference across the bucket *200*. The location of the cooling holes *290* may determine the temperature of every finite element making up the bucket *200*. The style of the cooling holes *290* may reflect the way in which heat transfer occurs across the walls of each cooling hole *290*. All these attributes together may create the cooling scheme provided herein.

[0033] For example, the present invention may provide a flow of about 1.11% W2 as compared to existing designs with a flow of about 1.31% W2, or an increase of about twenty percent (20%). Generally described, W2 is a measure of the mass flow rate of air traveling through the core of the turbine that enters into the compressor. Further, the bulk creep part life may be increased to about 48,000 hours. The overall unit performance may increase by about 0.3%.

[0034] It should be understood that the foregoing relates only to the preferred embodiments of the present invention and that numerous changes may be made herein without departing from the general spirit and scope of the invention as defined by the following claims and the equivalents thereof.